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WORKING PAPER
ALFRED P. SLOAN SCHOOL OF MANAGEMENT

COMPUTER IN THE ORGANIZATION*

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Synopsis

In its commercial form, the digital computer has been with us for only a decade and a half. Yet its profound significance for the future of civilization is already well established. This is a remarkable achievement for such a technological stripling. It makes us eager to anticipate the benefits that the electronic prodigy will one day deliver to us. But it also disturbs our sense of orderly history, and causes the more cautious and thoughtful among us to recoil from too unreserved an enthusiam for the brazen young technology.

This article steers a moderate course in assessing trends in the computer's further development and commercial application. It relates the future of the computer to the two centuries of industrialization and mechanization that led up to its christening fifteen years ago. The automation of the 1960's and 1950's was born of the industrialization of the 1900's, 1800's, and late 1700's. It came about in an atmosphere of human resistance to machines which was evident in the time of the Caesars, is apparent still today, and shows no sign of fading at any time in the foreseeable future.

The first part of the article cites the psychological forces which have retarded mechanization throughout the ages, and suggests how the same forces are now impinging on the progress of the computer. Countervailing forces are discussed. This part serves as an introduction to what follows.

The next three parts may be viewed as a short trilogy on the past, present, and future of the computer in the organization. They begin with a flashback that scans the pre-computer era, and examine how man in former times has been accustomed to organizing his work and himself. When the computer makes its entrance, the same organizational processes are observed at work within it. We study the pattern of these processes, and then preview

the new organizations to which they may lead. A few current examples of real-time computer systems are surveyed.

The fifth and final part is a postscript to the preceding analysis. Our technological optimism is tempered by consideration of the new social and moral problems that are likely to follow upon the computer's continuing advance.

PART I. INTRODUCTION

Computers come closest to ordinary people and everyday matters in their application to commercial affairs and the administrative concerns of government. The area known popularly as commercial data processing has proven ripe and receptive to the computer's touch. As a consequence, the use of computers in business and government has climbed rapidly since the first computer produced for nonscientific use was introduced into the United States Census Bureau in 1951. Few people then could have foreseen that tens of thousands of commercial computers would be humming busily in the United States by 1966. And few today can see clearly enough through the next fifteen years to envision the place these machines will occupy in our daily lives by 1981.

History suggests that man and his inertly inclined organizations tend to resist procedural modification, regardless of how outmoded and anachronistic their current methods may be. The medieval marketplace re-enacted Monday through Friday on the floor of the New York Stock Exchange vividly illustrates how long ancient practices can succeed in defying modern technology. Pre-nineteenth century mathematics still holds sway in present-day commerce, and the logarithm, dating back to the early seventeenth century, receives meager attention in many financial contexts where it has particular relevence.

Inertia is not peculiar to the nonscientist, nor is it found only in traditional occupations. Dr. Grace M. Hopper, who has been programming and supervising programmers since the first computer, complains that the computer programmer is just as loathe to change his adopted ways as the next fellow. Hanns Sachs, a student and colleague of Freud, pointed out that the Romans had a good knowledge of hydraulic pressure, and realized

its value for lifting great weights. But they used it only for shifting scenes in the Circus and other forms of amusement. Instead of building productive machines, for which they had adequate technical and mathematical understanding, they continued to employ their dwindling supply of human slaves. The Romans had strong economic reasons to seek substitutes for manual labor. Yet more of their mills were turned by slaves than by water power.

Without attention to man's psychological structure, it is hard to understand why the Machine Age did not arrive at least 1500 years earlier than it did. Sachs attributes the postponement to a narcisistic conflict: an abhorrence of anything that threatens to devalue the human body. The body was never so glorified and ennobled as it was in the civilizations of antiquity. According to Sachs,

> "The ancient world overlooked the invention of machines not through stupidity nor through superficiality. It turned them into playthings in order to evade a repugnance."

Other explanations would cite man's tendency to resist the new and espouse the old, his need for security, and his fondness for familiarity, even while exploring unfamiliarity.[1] These factors have been an important component of the psyche of mankind throughout the ages, and doubtless they will continue to be.

Only during periods of war fever, extreme duress, or agitated social change is innovation likely to conquer tradition in matters of procedure. Even then, progress can be slow. This past generation was no exception, as anyone acquainted with the halting manner in which many business computers were brought into the organization will readily

acknowledge. But there is reason to believe that the next generation will put the rule of custom and inertia to its severest test. The computer, due partly to a fertile marriage with communications, and partly to an enlightened mode of use, is beginning to come of age.[2] Its double impact is now being felt by the men of affairs whose decisions will be shaping the world of the 1970's and 1980's.

The first impact of the computer is its well advertised and amply substantiated contribution to scientific and technological advance. It is well known that without the computer there would be no nuclear reactor, no commercial satellite, no space program, and possibly no jet travel. In such ways as these the computer is aiding and abetting a much-observed increase in the complexity and pace of life. The world is getting smaller and its wants are getting larger. There are new urgencies and a sense of change. Informational requirements are mounting, and the need for comprehensive analyses grows keener. A military-like preoccupation with modern methods pervades industry. These conditions invite and encourage a recasting of procedural molds.

The second impact of the computer is its remarkable ability to help alleviate the same timing, volume, and computational problems that it shares in creating. But it can assist man meaningfully only when he is ready and willing to accept new ways. The first effect of the computer makes way for the second, and permits a more meaningful participation in the substance of man's activities.

The computer has not yet reached nerve tissue in most organizations, but it seems more certain all the time that it soon will. The form this will eventually take is still not clear, yet enough good developmental work is underway to permit speculation. Among those who have ventured to the crystal ball is Herbert Simon. Our discussion is greatly indebted to his writings.[3]

PART II. THE PAST

Specialization and the Division of Labor

If the dogs, cats, and birds that we keep as pets were given to analyzing their masters and making inter-animal comparisons, they would surely comment upon man's pronounced propensity to trade. Men exchange not only their wares and material possessions, but just about anything else to which they can attach value. In particular, with money serving as intermediary, they trade their services and productive labors. One man mends shoes, a second delivers milk, a third provides legal counsel. Each benefits from the work of the other, giving his own work indirectly in return.

This division of labor, known from the worker's point of view as specialization, is a prominent characteristic of all advanced societies. It is also present in primitive cultures, to a striking degree in the colonies of bees and ants, and significantly, in the internal organization of every living thing. In human civilization it attains its most versatile form. Appearing as an almost universal principle, it occurs in numerous contexts, from the classification of an economy into industries, to the breakdown of an industry into firms, to the patchwork of occupations and professional skills found in every community, to the differentiation of a fabrication process into tasks and movements.

A classic example of the last case was portrayed graphically by Adam Smith at the beginning of the Wealth of Nations. With the "very trifling manufacture" of pin-making as an illustration, he wrote:

> "a workman not educated to this business (which the division of labour has rendered a distinct trade), nor acquainted with the use

> of the machinery employed in it (to the invention of which the same division of labour has probably given occasion), could scarce, perhaps, with his utmost industry, make one pin in a day, and certainly could not make twenty.
>
> "But in the way in which this business is now carried on, not only the whole work is a peculiar trade, but it is divided into a number of branches, of which the greater part are likewise peculiar trades. One man draws out the wire, another straightens it, a third cuts it, a fourth points it, a fifth grinds it at the top for receiving the head; to make the head requires two or three distinct operations; to put it on, is a peculiar business, to whiten the pins is another; it is even a trade by itself to put them into the paper; and the important business of making a pin is, in this manner, divided into about eighteen distinct operations which in some manufactories, are all performed by distinct hands...
>
> "I have seen a small manufactory of this kind where ten men only were employed, and where some of them consequently performed two or three distinct operations. Those ten persons could make among them upwards of 48,000 pins in a day."

The type of task differentiation which Adam Smith was describing in this account of 1776 received great impetus from the industrial revolution, then just underway, and renewed impetus from the time and motion studies of Frederick Taylor's scientific management at the start of the current century. The emphasis was on increasing productive efficiency. The worker whose job was appropriately constrained was expected to become more skillful at it, being less sapped by the distractions and annoyances of

continual shifts between unlike tools for dissimilar operations in scattered places.

The negative aspects of specialization have been portrayed eloquently by Charlie Chaplin in Modern Times, and also forcefully, if not so amusingly, by industrial and social psychologists. An entire human relations school has grown up in reaction to the cold formalism of scientific management. This school has brought psychology to the organization, but it has not reduced the importance of specialization as a way of life.

Among its strengths, specialization enables the conscientious worker to become better at his job through practice and focus. It gives rise to training programs, trade magazines, professional associations, and standard job descriptions, all of which provide valuable communication channels among companies, as well as interfaces with schools and labor markets. Work improvements are also achieved through the control methods and analytical techniques practiced by a separate breed of specialists, including the industrial psychologists. These specialists, as they come into being, are typically of a higher educational, intellectual, and salary level than the man on the line. Thus, labor becomes divided vertically as well as horizontally. The vertical strata include the managers of the workers, and also the managers of the managers.

Organization

The horizontal and vertical divisions of labor are made cohesive by man's creature, the organization. The organization furnishes rules and goals to unite the varied divisions of labor into purposeful activity. It deals in the marketplace, negotiating for resources, and also packaging, storing, advertising, and distributing products. All of these activities,

as well as the production and control functions, are differentiated in the large organization.

The organization is typically hierarchical in both its structure and growth pattern. Specializations are grouped. Groups of workers on one level report to members of groups of a higher level, who report to members of groups of a still higher level. The hierarchical structure occurs naturally in the evolution of an organization. It can be rationalized on the basis of its simplicity, flexibility, generality, and adaptability. In addition, it serves to economize on the required number of information channels, and simplifies the assignment of authority and responsibility. The form is found in all manner of things, from cellular matter to programs and list-structured information in a computer.

The hierarchical form is not without its disadvantages. With information physically dispersed around the company--along with personnel, supplies, inventory and work-in-process--locating needed data can be a time-consuming and grueling affair. Informational problems, and communication and control difficulties in general, can bog down the operation of a large company and create unnecessary crises. One attempted solution has been the decentralization of functions, goals, and incentives through the institution of divisions and profit centers. But decentralization is sometimes a mixed blessing, since it tends to proliferate positions, duplicate activities, and create local goals that can run orthogonally to the objectives of the organization. Streamlining the information system may be a better solution, and we shall have more to say on how modern computer concepts are beginning to open this alternate route. The result is that the issue of centralization vs. decentralization is currently taking on renewed interest. Companies are introspectively re-examining their

rationale for decentralization. Some observers believe that the computer will eventually reverse the trend toward decentralization that has characterized industrial growth over the past thirty years. They cite as examples the current computer-integrating activities at International Harvester, United States Steel, Standard Oil Company of New Jersey, and even at General Motors, the exemplar of decentralized operations.

Whether these companies and others will ever truly recentralize is a moot question, even assuming an integration of their information flow. Decentralization can have many of the advantages accruing to other forms of specialization; and it can be very effective in distributing incentive mechanisms down the hierarchy. A review of organizational structure once every so many years is all to the good, however, whatever the decision. The same holds true for related studies of information and communications. Such are the hidden benefits of the computer, which has a way of throwing these vital company matters into sharp relief.

Within the company hierarchy, three distinct levels are definable conceptually. These levels, which may or may not be physically separable, are:

1. Strategic planning
2. Management control
3. Operations

The top level, in theory, sets the objectives for the company, reviews and modifies these objectives as the situation warrants, determines the material and personnel required to pursue the objectives, helps to organize and allocate these resources, establishes policies that allow the lower levels an adequate measure of autonomy and self-regulation, takes remedial action when policy fails, decides on questions of organizational structure, and meets

operating crises when lower levels cannot. At present, crises tend to consume a disproportionately large amount of time. Often, these crises can be attributed to a defective information system.

The middle level serves as a buffer to the top, insulating against the vibrations and oscillations of daily operations. Its function is to control the acquisition and use of resources in pursuit of company objectives within the policy lines set from above. Its orientation is tactical. It is currently much more occupied with matters of operation, and with urgencies arising from below, than it should be. Again, many of these urgencies can be traced to poor information and communication.

Operations is the level at which the daily business of the company takes place. Difficulties on this level tend to filter up the hierarchy and affect the upper levels. The same may be said of amelioration of these difficulties, and improvements to operations in general, including those incident to automation.

Accumulation

One of the most important roles of the organization is in coordinating its differentiated elements. This includes routing information and controlling the flow of work.

The simplest form of flow control is that found on an assembly line. The automatic movement of material from one station to the next is precisely timed so that none accumulates at the stations under ordinary conditions. It is analogous to the conduct of a relay race, or the operation of a telegraph repeater without storage.

An assembly line, however, is not a good model of the typical organization. More generally, orders and information arrive in uncertain ways, moving

irregularly along variable paths through an incompletely articulated network of nodes. The job shop is a more appropriate model.

In a job shop, jobs queue at the work stations. This is partly an unavoidable result of the stochastic flow, and partly a deliberate measure to keep machines and/or people busy. Absolute efficiency master-planned from above is not feasible. The alternative to accumulation is costly over-capacity.

Even when the flow is steady through fixed steps and scheduled in advance, as it is in many large clerical operations, the practice of accumulating work is often used to keep facilities or people fully loaded and productive. Utility bills, payroll checks, and premium notices are not sent out individually, but in *batches*. Payments are not posted to the ledger as they are received; checks are not dispatched to the clearing house as they are honored; and stock certificates are not issued as sales are consummated. All of these transactions, and many more, are batched before being executed. The batching of transactions introduces a delay into the transfer and receipt of information.

The queueing of jobs in a job shop, the batching of transactions in a clerical operation, and the carrying of inventories, in general, are natural concomitants of the division of labor. The more we differentiate, the more they appear. They result from our attempts to make specialization as efficient as possible in a complex and uncertain world. There is almost always an implicit holding cost attached to these accumulations. We may regard it as a price of specialization. It can be appreciable.

Mechanization

In refining tasks under specialization, an ultimate of sorts is reached when a task is mechanized. Many tasks originally fashioned for men are now

performed by automatic devices. A specific instance of mechanization might result from the inspiration of a manager, an outside expert, or the worker himself. Adam Smith tells of the boy who was employed to open and shut the communication between boiler and cylinder as the piston ascended and descended in one of the first fire engines. Preferring the companionship of his playmates, the boy observed that a string connecting the handle of the valve to another part of the engine would regulate the valve properly without requiring his presence. This led to a design improvement of major importance.

A similar and perhaps better known anecdote is the story of Thomas Edison as a young telegraph operator. His distaste for routine, and his ingenuity for finding ways of avoiding it, led to one of the early versions of the automatic telegraph repeater, and also to a forerunner of the messenger call box. The year before he built his repeater, when Edison was sixteen, he worked as an operator on the 7 p.m. to 7 a.m. shift. In order to be able to experiment during the day and preserve his nights for sleeping, he rigged a simple mechanism to an alarm clock. It transmitted a required "six" signal to his supervisor on the hour throughout the night.[4]

Machines often develop as the product of a series of mechanizations of previously differentiated manual tasks. Even when a machine like the steam engine or telegraph represents a quantum jump in technology, later modifications and refinements are more typically incremental in nature. Sometimes the steps in the mechanized operation correspond exactly with the tasks they replace. The manufacture of pins is today accomplished by a single machine. It turns out several hundred thousand pins per hour, while going through most of the same steps that Adam Smith observed in the eighteenth-century manual operation.

At the same time that mechanization releases the worker from his narrow niche, it may require him to retrain and readjust. Mechanization does not provide immunity against the persistent forces of specialization. They continue to impinge, as the computer operator who has been assigned to the care of magnetic tape mechanisms will testify. It is as though a recurrent cycle of natural law were taking effect. Man divides his labor into separate tasks to achieve greater productivity, then performs these tasks himself until he finds ways to mechanize them. The new jobs that emerge also are gradually differentiated, and the process repeats. The cycle has a net beneficial effect. Over the long term, productivity increases.

PART III. THE PRESENT

Automation

Automation is the current phase in two centuries of expanding mechanization, and represents a movement away from the mechanization of primarily physical effort toward the mechanization of mental effort. The name arose during the 1950's upon the appearance of the commercial computer and automatic process control. To many people it represents the most recent intrusion of the machine into man's private domain, across a boundary that is constantly receding.

To Hanns Sachs, in his pre-automation analysis of 1933, contrivances like the plow and spinning wheel, which simply helped man do his job more easily and better, have always been palatable. What has been distasteful, at least until the Industrial Revolution, was the thought of machines like the steam hammer and locomotive, which did man's job alone once set in motion, and which required man only as master-mind in control. Now that we have the computer, even the man in the driver's seat is dispensable, as borne out by self-landing jetliners and completely automatic railways. The age-old man vs. machine conflict has shifted and focused onto the computer: what it should and should not be doing, and how much of our decision making and control activities we can and should delegate to it.[5] The blunders and short-comings of no other machine attract nearly as much journalistic fervor and anecdotal attention as those of the computer.

The computer was born in the scientific laboratory and spent its childhood composing lengthy numerical tables. It made its mark in the handling of large volumes of routine calculation, and this reputation stuck for many years. It may have stuck as long as it did partly because

of our narcissistic attachment to nonroutine, creative activities. In any event, an idea as complex and novel as the computer takes a while to sink into man's collective comprehension. Most people, including those who stood most to benefit from the now proven versatility of the computer, initially took a very narrow view of its prospects.

When Eckert and Mauchly formed a company to build the Univac computer for commercial application in the late 1940's, it seemed that just a few machines might take care of the routine business calculations for the entire country. Some of the engineers assigned to the project wondered aloud over their sandwiches what they were doing working on equipment of such questionable potential and limited market. Executives at the International Business Machines Corporation are known to have had even graver doubts.

The Univac, like most of its successors, was a general-purpose machine. In principle, it was good for just about anything; but people speculated on whether, in fact, it might be good for nothing. Not the least of the problems was the uncertain reliability of computers in those days.

Under the circumstances, it is not surprising that the early commercial machines were used primarily for the most routine of clerical tasks. These tasks were usually selected with an eye to the status quo. It was all right if a few workers were displaced; in fact, computers were and still are often sold on the basis of the number of workers they will supplant. What was verboten was structural disruption to the organization.

The first Univac for strictly business application was installed at the General Electric Appliance Division in 1954. It was set to the task of preparing the payroll. After a great deal of agony and mishap, the operation finally succeeded. Payroll became a bread-and-butter application.

Other early commercial applications included billing and customer accounting for banks, insurance companies, and public utilities; also stock control in manufacturing, warehousing, and distributing operations. For the most part, these tasks were automated along lines previously established for the differentiated manual operations. Transactions on cards flowed to the computer by the trayful from keypunch, verifying, sorting, and collating machines, much as they had flowed before from one set of clerks to another. Since the computer was much faster than its co-workers and predecessors, and allowed just one point of entry at a time, transactions became batched more than ever. An additional operation was established to convert cards to magnetic tape for faster input to the computer, giving rise to what became known as the batch tape.

Computer Routines

The new machine in the organization was as subject to the forces of specialization as everyone before. The computer was set to work initially on existing tasks that were narrowly defined and routine. But it was not to be put off so easily.

Because of its general-purpose nature, and because of continuing technological improvements in its speed, capacity, and reliability, the computer was able to take on additional jobs in abundant variety. This was not defiance of the forces of specialization. The division of labor was now occurring within the machine.

Computers are constructed from transistors, diodes, magnetic cores, and most recently, monolithic integrated circuits. These are specialized elements with carefully prescribed functions which they perform with hair-trigger precision. But theirs is not the division of labor within the machine to which we allude. The sequential operation of these elements

is controlled by programs of instructions or logical steps. It is in the organization of programs that a significant new discrimination of specialties has been taking place.

An industrial concern grows by hiring more workers and enlarging capital plant. A computer system grows by increasing programming capability and expanding hardware facilities. The simplest and most convenient way of increasing programming capability is by the addition of routines. A routine is a set of instructions for performing some distinguishable function. As uncouth as it may seem at first, the analogy that others have suggested between the computer routine and the human skill or worker is valid and meaningful.

The concept of a routine came into existence along with the first computer. It is the programmer's way of coping with complexity. The division of a program into specialized routines parallels the division of human labor into skills or tasks. If fact, in a large programming project which requires a team effort, the two are directly related. A structuring of the overall program into routines or modules permits the project manager to assign separate modules to separate members of his team. They are able to work in relative isolation, responsibilities are fixed, program checking is simplified, and the project can proceed along several lines simultaneously.

The modular approach is widespread. A group of us at Harvard University used it in 1957, for example, to program a demographic model of the United States economy.[6] One programmer was appointed to the death and divorce routines, another to the birth and marriage routines (she soon became engaged), and so on. When simulation made it apparent that the birth routine was theoretically and behaviorally defective, it was easy to reach in and substitute a more valid routine in its place. This illustrates another advantage to the modular approach.

Almost all large programming projects have been modular in structure. Among the better known are the SAGE system for continental air defense, the SABRE reservation system of American Airlines, the Project Mercury system to put a man in space, and the Project MAC time-sharing system at the Massachusetts Institute of Technology. Not all of these projects were as modular at the outset as they eventually became. Modularity tends to increase with complexity, and also with wisdom acquired from the sharp lessons of experience. But modularity is not a panacea, as the 1800 man years spent programming the initial SAGE system might suggest.

Program Organization

Specialization creates a need for organization. This applies to the division of programs as much as to the division of labor. As a first requirement of organization, the separate elements must be able to communicate with each other, group together, and work cooperatively. The programming profession has supplied various devices for this purpose, including the subroutine and the subroutine call. A subroutine is a routine whose function is sufficiently well defined and specific to permit it to be standardized and made generally available. Subroutines may call themselves and each other to any depth. Conforming to standard conventions, a closed subroutine uses information cited by the routine that calls it, performs its function, then returns control to this routine. Since a subroutine can be called from anywhere at any time, the effort that goes into its creation may be repaid a millionfold.

Organization also requires that the separate elements be coordinated from above. In a simple computer operation, the flow of control among routines is scheduled by a main program. The main program may be thought of as a list of work to be done. Writing the program schedules the work. Devices

designed to facilitate programming, therefore, also facilitate the achievement of coordination among routines. The most important such device to date has been the compiler. The compiler allows the programmer to compose in terms of named blocks of machine instructions, instead of machine instructions themselves. The language of the compiler is of a higher order than the primitive language of the machine. The expressions of the higher-order language are closer to the images in which a person normally thinks.

Among the better-known compiler languages have been Fortran, Algol, and Mad for scientific computation; Cobol for commercial application; Jovial for military application; and Simscript for simulation. PL/I is a current addition to the list.

In the use of a Fortran-type compiler, the main program either directly or indirectly determines the sequence in which subroutines and named blocks of instructions are called. Simscript is different. It uses a dynamic schedule of subroutines known as an events list. Like a main program, the events list causes calls to the subroutines whose names appear on it. Unlike a main program, its content is changed continuously and dynamically during the execution of these subroutines.

The concept of a main program is pleasing and easy to understand. It shares a characteristic with an assembly line and the cycle of a washing machine. It moves by steps, one at a time, in sequence, from beginning to end; then perhaps repeats. Steps may be single machine instructions, or named blocks of instructions and subroutines.

The events list is only slightly more complicated. Its steps, known as events, are scheduled dynamically during execution, rather than being fixed in advance by the programmer. Even the events list has the basic simplicity of being a master list which is consulted serially, one item at a time.

The simplicity is undermined by computer systems which keep several programs active at once to improve equipment efficiency; it is completely shattered by systems that interact with external processes in real time.

Real-Time Systems

The SAGE system accepts sightings as they are made from radar sites, observational aircraft, and picket ships spread over a radius of several hundred miles. The data must be processed upon arrival at the computer, and summarized immediately on display screens and scopes for Air Force evaluation. If interception or other defensive action is required, the computer must act as advisor and controller while continuing to carry on its normal operations.

Other real-time systems have similar responsibilities and timing commitments, differing only in degree from those of SAGE. SABRE serves over 1000 reservation clerks at agent sets around the country. Their transactions come in individually at unpredictable times, placing an uneven load and wide variety of demands on the system; yet SABRE is tuned to a response time of under three seconds. The Project Mercury computer guided a man in space flight on the basis of an analysis of multitudinous measurements that fed into it continuously. Project MAC "time shares" a large computer among numerous concurrent users who call up over conventional telephone lines at random times, place requests that cover almost the entire spectrum of things a large computer is capable of doing, and expect the kind of interactive service that gives them the illusion that each has the machine to himself.

In real-time systems, several internal and external processes are active at once, their timing is asynchronous and uncertain, multiple programs cohabit

memory jobs queue as in a job shop, and control is distributed. There may still be a master scheduler or executive, but its operation and that of the subroutines it calls can be interrupted at any time.

Without notice, new work enters from an on-line terminal; information previously requested from a slow-access storage device is announced ready for delivery; the alarm of the computer clock rings to note the time of day; a certain periodic requirement is in need of attention; an error or emergency condition is sensed. Such contingencies necessitate immediate action. The routine that happens to be running at the moment cannot be expected to know what to do. Nor should this be the responsibility of the executive. Its scope of action and tolerance for complexity is as limited as that of the next program. Like the head of the company, it must delegate.

The form that contingency planning takes is another example of specialization at work within the computer. A special routine is provided for each class of contingency. When a contingency arises, the appropriate routine is called. After necessary action has been taken, normal execution is resumed from the point of interruption.

As might be surmised under the circumstances, real-time systems can have hundreds or thousands of routines and millions of instructions. The routines are sometimes called programs, and fall into one of the following two types:

1. control, supervisory, executive, or monitor programs
2. application, operational, or user programs

The fact that the first type of program is control-oriented, whereas the second type is task-oriented, makes it tempting to draw a parallel with managers and workers. A control program, however, may have few characteristics that we associate with managers. And an application program can be more like an entire division of a company than like a single worker.

An illustration of this is our OPS system at Project MAC.[7] To the time-sharing supervisor, it is just another user's program; yet, it is actually a complete operating system with its own retinue of control routines and a wide assortment of subroutines and operational programs known as operators. There is an operator corresponding to each of the customary statements in higher-order languages, and also to individually tailored and arbitrarily complex compounds of these statements. This gives the user a programming capability that comes closer to his thought processes than do the statements of a higher-order language by themselves. One operator solves general linear programming problems by application of the Simplex Method. Another does a multiple regression analysis. A third locates the critical path in a Pert network. A fourth performs a general computation involving vectors and matrices. A fifth smoothes a time series, providing an economic forecast. A sixth schedules an event during a simulation run. A seventh prints information in tabular format. And so on. Within the OPS system--a user's program to the time-sharing supervisor--there is room for almost infinite variety.

In summary, we are not proposing a precise isomorphism between the elements of a computer system and those of a company organization. Even if it were possible, too much depends today on the particular application and configuration of equipment. Furthermore, whatever mapping resulted would rest on the uncertain foundations of a young and still changing field of programming. What is interesting and important is that the same kinds of organizational devices that have proven useful in human organizations are also showing up more and more in the organization of programs. There are multiple levels of control along the vertical dimension, differentiation of functions along the horizontal dimension, and a general tendency toward hierarchical forms in program evolution.

In those cases where programs and people are (or will become) interchangeable, the relationship between organizations of programs and organizations of people gets to be more than an intriguing analogy. Suppose that a company has a real-time computer system participating as a central instrument of operations. Suppose, like the OPS system at Project MAC,[7] it is open-ended and able to grow easily and assume new functions. The routine it employs to store away incoming transaction data does the work of a team of file clerks. The routines it has to make this data available on demand to customer representatives, and to summarize the data in periodic reports to management, are like staff assistants. To assimilate new services and take on additional business, the company can either expand its work force by hiring employees with the requisite skills, as has been customary, or it can make equivalent extensions to its real-time programs. It can also do some of each.

In this way, the real-time system is likely to become a vital part of the company organization. In the ultimate picture, the two parallel organizations of people and programs may blend together and appear as one, just as organizations of people and machines have tended to do in the past. This possibility will be explored further now in our consideration of the future.

PART IV. THE FUTURE

Current Trends

Our way of dealing with the future will be to align the historically observed forces that we have discussed (eg. differentiation and mechanization) along a vector of the currently perceivable trends (toward real-time systems, random access, and time sharing), and then project forward.

Real-time systems are already firmly entrenched in the military sphere, and they are fast gaining favor in business and industry. They seem destined eventually to win at least as broad a commercial acceptance as their batch-processing predecessors did before them. Real-time systems generally have most or all of the following key attributes:

1. direct (real-time) involvement of the computer in an external process;
2. a network of remote (tele) communication terminals, each of which transmits bursts of data to the computer sporadically;
3. direct (on-line) entry of the data into the computer without any externally noticeable accumulation;
4. transaction-by-transaction, rather than batch-by-batch processing of the data;
5. arrangement of information storage internally in randomly (as opposed to serially) accessible form.

The technology for real-time systems is relatively well advanced, thanks partly to existing military applications. Terminal equipment, however, especially that providing for graphical input and output, is still too expensive. In addition, the state of the art in real-time programming is as yet at an early stage, and the present tariff schedules and modus operandi of the communications

companies, who in the past have designed mainly for voice communications or dedicated data lines, are unrealistic for the transmission of scattered data bursts. Nevertheless, despite these temporary obstacles, real-time systems have been making decided inroads.

In the transportation field, several airway and railway companies have followed the lead of American Airlines and installed Sabre-type reservation systems. Soon real-time computers will be landing jetliners through heavy overcasts, scheduling railroad freight-yard activities and the movement of box cars; running and spacing the high-speed passenger trains of the Bay Area Rapid Transit Line in San Francisco; and guiding vehicular traffic in large municipalities. These real-time systems for controlling transportation may be linked someday with each other, and with similar systems for hotels, motels, car rentals, and travel agencies, to provide integrated regional and national systems.

Real-time systems also have been gaining entry into financial circles. Numerous savings banks have installed on-line teller systems; commercial banks are beginning to convert such jobs as demand deposit accounting and stock transfer to random-access operation; insurance companies are planning to make centralized customer records available on-line to their agents in field offices; a number of quotation services are available for dialing up a computer to get security prices; and the New York and American Stock Exchanges are embarked on streamlining programs pointed toward the eventual automation of all floor activities, with the possible exception of the specialist who "keeps the book" and "makes the market." It is not overly fanciful to foresee the day when the bulk of trading and financial transactions will be carried on from office to office electrically over the facilities of large computer-communication networks.[8] The implications for the future of our cities and the functioning of our economy are far-reaching.

Real-time systems are not restricted to large enterprises. Smaller companies can store their records remotely and subscribe to on-line computational services at any of a growing number of the established service bureaus, as well as at several new firms being set up expressly for this purpose.[9] The Keydata Corporation in Cambridge, Massachusetts inaugurated its on-line, real-time utility-type operation in November of 1965. Some of its clients are wholesale liquor dealers. Their clerks type invoices for customers at the time of sale from a teletype terminal in the home office. The terminal is connected to the Keydata computer by leased telephone lines. The clerk identifies the customer by number, and types in stock numbers and amounts of the items sold. The computer fills in the date, invoice number, name and address of the customer, prices, and a verbal description of the items, all of which it has stored in its files. It also calculates and types price extensions and sums, and checks for clerical errors. All in all, it types about 80 °/o of the information on a typical invoice. Since it retains all information relating to the sale, the computer is able to perform inventory control and provide sales analyses with little additional effort.

There are several important real-time developments on the industrial scene. The Lockheed Missiles and Space Company has had an Automatic Data Acquisition System in continuous operation since March of 1962. The system provides for the remote collection of data on work flow from over 200 input stations in factory locations, which are connected to two on-line computers and a large random-access disc file. Also attached to the computer are 25 remote inquiry/reply stations from which timely information can be obtained on such matters as the location of shop and purchase orders, inventory levels, and labor charges. The system covers the movement and control of over 200,000

separate items situated in more than a dozen shops spread over a 300-mile radius around the Lockheed computer center at Sunnyvale, California. It is a very successful operation and has saved the company millions of dollars in its Polaris and Agena programs, despite an initial eruption of resistance and resentment by the factory workers who must feed status changes to the system. The big-brother ogre seems to have subsided, due partly to training programs and partly to restrictions placed on the potentialities for intrusiveness by management. Hundreds of jobs in the area of purchasing, expediting, and production scheduling have become superfluous. The displaced employees who wished to remain at Lockheed have been assigned elsewhere in the company. Supervisors and their managers have been relieved of much of the oppressive atmosphere of chaos and crisis, and they now can devote more time to planning and coordinating.

The Westinghouse Electric Corporation is about as far along in systematic thinking about real-time systems, and also in implementation, as any industrial concern today. Their real-time Tele-Computer Center in Pittsburg is becoming the nerve center of the corporation. It has been doing message switching for the Westinghouse teletype network since December of 1962. Today it serves about 300 plants, field offices, warehouses, repair centers, and distributors throughout the United States and Canada. By capturing data from the messages it receives and transmits, the computer has been able to take over a significant amount of inventory control and order processing. It is actively assuming other functions, such as production control, as quickly as feasible. Improvements in service and operations have been dramatic. Since shipment is initiated at the time of an order from the closest warehouse that has the item, customers receive faster delivery; salesmen get information on stock availability and prices

in minutes instead of weeks; sales statistics are updated continuously; and inventory replenishments are requisitioned automatically. The scope of timely information which the system makes available to management on the divisional as well as the corporate level is broadening all the time, as more operations go on-line.

Westinghouse mechanized its cash flow in 1964 by means of what it calls a Cash Management Information Program. The program operates through the Tele-Computer Center and over the corporate teletype network which has terminals at the headquarters Treasury Office, all Westinghouse Divisions, and a central bank in Pittsburgh. Financial receipts and disbursements of each of the Divisions are transmitted to the computer and recorded in the appropriate accounts as they occur. Westinghouse has approximately 250 regional bank accounts supplementing its one central account. Whenever a disbursement threatens to deplete a regional account, the computer automatically orders a replenishment from the central bank. The message is printed out at the Treasury Office, where it can be intercepted. The Treasury Office can itself initiate transfers of cash to or from the central account. The Office monitors the balance in the central account continuously, and invests excess funds in marketable securities, notifying the computer as it does so. The net result of these procedures is that the book balance in the payroll and disbursement accounts can be kept as low as desired, funds that were formerly idle are now at work earning interest, and the company's current cash position is known at all times.

The Cash Management Information Program is elementary in concept, but profound in its implications. From a conceptual point of view, it is just another semi-automatic stock control operation. Cash is an extra-sensitive commodity, however. Its management is normally handled at the very top

stratum of the company, in contrast to the control of inventory and production, usually found at the operational level. Like other forms of inventory control, cash management is largely programmable. As an early example of the computer reaching up to the apex of the company, it is in the vanguard of the procession of future top management applications under consideration or already underway at Westinghouse, General Electric, IBM, Standard Oil of New Jersey, and many other large corporations. It also supports, with a little extrapolation and imagination, our earlier suggestion of a supra-company, inter-bank financial information network that may one day automate most financial transactions around the country and perhaps the world.[8]

Westinghouse is actively working on a video display device to present financial information graphically to executives for planning and control. The display is located at headquarters, twelve miles from the Tele-Computer Center which drives it. In a recent letter, Lou Hague, former director of Business Systems at Westinghouse wrote:

> "We have completed the programming of the initial displays for demonstration purposes and are now in the process of testing and debugging the program. Our approach here was to start with something with which our executive management is familiar--that is, a reproduction of the graphs which they use for reviewing the financial operations of the Company. We are able to display in great detail financial forecasts, actual accomplishments, and any resultant variances for any of our 65 divisions, six Groups, or the total Corporation. We can extrapolate trends based upon historical data and mathematically show control limits for each category being examined. At the present time, our inputs from the divisions are limited to the conventional monthly accounting cycle. As you will recall, a parallel project is to get all of our operations on-line in real-time as quickly as possible. This will considerably shorten our reaction time from the generation of the data in the division to having the results displayed here in Pittsburgh. Our estimate is that it is going to take us approximately five years to accomplish this; but, at that time ... we will be able to display performance criteria upon demand."

These selected examples have illustrated real-time systems automating operations, supervising logistic flow, facilitating customer transactions, and in the same processes, collecting and organizing timely information for management. The resulting benefits to the executive are both direct and indirect. Since today's executive prides himself on being an alert innovator and vigorous competitor, and since others expect these qualities of him, he is propelled by his self-image plus the forces of competition into active support of the computer. This drive tends to offset the more primary proclivity he might have to dig in and hold on to traditional ways. Whether this support will be as robust once the computer begins to nudge him aside (a bit), is an interesting question. The middle manager is already being nudged, and his ambivalence shows.

If the manager is to take full advantage of the current, comprehensive information soon to be placed at his fingertips, he will be pressed to delegate some portion of his decision activity to his swifter machine assistant. This delegation will come about as both the cause and effect of significant changes in the decision environment. Many of the analyses now accomplished by the batch-processing computer (using methods of operations research, statistical decision theory, heuristic programming, econometrics, and simulation) will be moved up to real time, perhaps in simplified form. It would be naive, however, to suppose that the manager's thought processes will suddenly become synchronous with the outpourings of these analyses, simply by seating him at an on-line terminal of the system. There will have to be mutual accommodation, and certain analyses will undoubtedly remain asynchronous. But the way to get experience and understanding in these matters _is_ to begin to put the manager and his staff on-line, and place analytical tools and models at their disposal. Preliminary work along these

lines is now going on at the General Electric Company, at Project MAC, and at a few other places.

What makes this exploratory work possible is the recent advent of time-shared computers, which are able to dispense their considerable information storage and processing capabilities to many simultaneous on-line users without a noticeable sacrifice in responsiveness.[2] The largest and most versatile of the exisiting time-sharing systems allow each user to operate the computer almost as though he were in full control. In contrast, most real-time systems stereotype and constrain the user's actions. Although time-sharing systems generally have not run concurrently with other real-time operations, in principle they can. In the discussion that follows, we postulate a system that time shares the computer for managers and their staffs, while running company operations and collecting transaction information in real-time.

On-Line Synthesis and Control

There are two ways that man can interact with the time-shared computer. The first is in the structuring of ideas and solutions to problems. For simplicity, we refer to this kind of activity as synthesis, even though it has decided analytical components. Synthesis includes the construction of programs and building of models. The computer is used to check the syntactic or behavioral validity of each unit as it is added, and permits an incremental approach. The OPS system takes its name from its general usefulness in On-line Process Synthesis.[7]

The second form of interaction is in the execution of programs already synthesized, at least partially. Man can insert himself into the operation as an adjunct to synthesis during a preliminary or intermediate state of construction. OPS also has this capability.

A key purpose of human involvement in a computer operation is as a means for incorporating judgmental and otherwise amorphous aspects of a process. A trivial example is the reservation clerk at American Airlines who translates the customer's perplexity in the manner to which SABRE is accustomed. A more meaningful example is the heuristic research worker who personally explores the space of possible solutions to his problem by means of an extended interchange with the computer and its programs. Most germane to our subject is the decision maker who has the computer signal him on an exception or interval basis, and relies on it for the information he needs to make a decision. The man in the Westinghouse Treasury Office at the on-line terminal of the Cash Management Information Program is a good example. Today he uses the computer to display cash levels on demand and to notify him when a pre-set threshold has been reached. Tomorrow he will also use the computer to ask unstructured questions and explore a variety of different possible futures, while seeking through his chain of on-line decisions to secure the version of the future he likes best.

The Automated Information System

We spoke before of a recurrent cycle which seems to govern the mechanization of human effort. In the first phase, work is differentiated; in the second plase, tasks able to be mechanized are delegated to machines. Then new jobs emerge and the phases repeat.

We now conjecture on how this cycle will manifest itself in future information systems. For simplicity, we assume a company with one integrated real-time information system and managers (or human controllers) at the consoles. The system may be built around a single centralized computer, or a distributed network of computers. Each man is responsible for monitor-controlling a separate aspect of the company's operation. In addition, he

is provided with ample time and encouragement to isolate the more definable parts of his responsibility, and gradually synthesize them as new application and control programs. He runs the new programs at first experimentally, with a watchful eye, and eventually incorporates them as permanent and integral components of the automatic operation. He is assisted by specialists in heuristic programming and simulation modeling.

By continual introspection and the shedding of selected parts of his function, the enterprising manager can become progressively more productive to the company. His job keeps changing, but his contribution grows larger rather than smaller. His superiors should make every effort to have this important fact reflected by his income and position, since narcissistic resistance to automation in this setting is likely to be as at least as strong as ever.

Viewed from above, an intriguing interplay of centripetal and centrifugal forces can be discerned. Tasks that show the computer to comparatively best advantage are drawn inward into the body of programming; tasks that prosper more from the human touch drift outward to the men at consoles (and beyond). Many of these tasks would not be identifiable today. The environment from which they emerge will be shaped by a new kind of commerce among new kinds of organizations.

As the company expands its operations and diversifies its business, it will add new programs and people to its information system. By its basic design, the system grows easily. It is also easily modified. Additions and modifications are kept flexible (interpretive) until they perform to satisfaction. Then they may be compiled (consolidated into direct machine code) for a gain in running efficiency. Compiled programs may themselves be refined and made more efficient by a continuing policy of replacement

and improvement. Over a period of time, the system tends to become larger in scope and better in detail.

Acquisition of new programs by the system is not unlike learning in the human being. A new program in interpretive form is similar to a response or behavior pattern that is being tried out tentatively. A compiled program resembles a habit, although it is generally not "hard to break" unless it is deeply ingrained in the system's central core.

The Automated Memory

We can carry the analogy with a human organism one step further by adapting a three-way classification used by Edward Feigenbaum in a model of human memory.[10] The memory of the information system may be viewed as consisting of:

1. A temporary or buffer store, containing information received or known somewhere in the company, but not yet generally available.
2. An active or short-term store, containing information that is generally accessible to authorized persons, and is used by them in daily operations.
3. A passive or long-term store, containing information retired from the active store, and available primarily for running audits, answering questions, and conducting historical studies during non-peak hours of computer operation.

Today the temporary store of the company includes cards, drawers, vest pockets, cabinets, and tapes full of batched transaction data waiting to be processed and summarized. The data is spread around the organization, up and down the hierarchy. It may be days or weeks before some of it gets into the active store and becomes available for operations and decisions.

In the future information system, the bulk of this same data will feed directly into computer memory from terminals at the site of transaction, just as data on the flow of hundreds of thousands of inventory items currently feed into the Automatic Data Acquisition System of Lockheed from hundreds of remote terminals. There will still be an accumulation of data in the future system, just as there will still be a division of labor, but like the division of labor it will occur within the machine. A datum will wait in the input buffer of the computer but for a second or two until its personal input routine picks it up and puts it in active store. The routine will place it in one or more lists and reports, as determined by its nature, and will link it explicitly to related information already stored. Other routines will make the information in the active store flexibly and quickly accessible to persons with the need to know.

The Lockheed experience illustrates how improved information can lift the fog of needless complication and confusion that besets many companies. The manager, relieved of haunts from the past, is able to devote himself more to consideration of the future.

Management control of operations is often viewed as a feedback system. Suppose that operating performance appears to be departing from a desired state, perhaps resulting in a perceived crisis. Under pressure, the manager makes a decision, such as hiring more workers or purchasing more material, which he intends will correct performance. If his information is poor, he may be as ineffectual or even perverse at times as a thermostat which cannot sense temperature properly.

Better information for better control is the first expected benefit of an automated memory. The more profound and longer-range hope is for a system that will allow the manager to operate on a feed-forward rather than

a feedback basis. With the help of simulation models, he will attempt to anticipate difficulties before they occur, and take preventative action. But attainment of this management Utopia will require substantial work of the intellectual kind. Construction of the automated memory, on the other hand, is feasible with current technology and the present state of programming sophistication. Thus, timely information made easily accessible is likely to be the first big dividend of the automated information system. Aside from the dollars it will save, and this is already well substantiated by the Lockheed and Westinghouse experiences, it will pave the way for further automation, and give the company a new coherence and sense of unity.

PART V. POSTSCRIPT

Life with the computer is certain to be different. The organization will function more smoothly and efficiently, and it will be more productive; yet there will be no long-range massive unemployment, nor will there be the inundating overabundance of goods and services that some prophets of doom have predicted. The computer will become much easier to use, and generally more accessible to the nonspecialist; people will come to take it for granted. Job descriptions will be drastically altered. Life will indeed be different, but whether it also will be better depends on our ability to anticipate and plan.

It is self evident in this day of nuclear armaments that what may become technologically feasible may not be socially desirable. The same devastating power that makes the H-bomb so effective as a deterrent to war, far overshadowing any of its predecessors, also makes it a dire menace to the safety and security of humanity. The same impressive qualities that make the computer a prospective boon to the operation of the organization, also render it a potential threat to the privacy of the individual and his self-identity.

Much has been written on the presumed pernicious fallout of the computer: the machine cult of impersonality; clandestine invasions of privacy by unscrupulous persons, including overzealous agents of the government; criminals misusing future information systems; and so on. The dangers are real, and they should not be waved aside, especially by computer scientists who are today in the uncomfortable position that the nuclear physicists occupied in the thirties. It should be very clear, however, that the possible evils stem from the way man uses the computer, not from the computer itself.

The blinking lights of the display panel are not the eyes of a Satan eager to corrupt humanity. Information systems of the future will assume the character that man designs into them. Prevention of abuses is an important part of the design problem.

Man must regard himself more closely now than ever before, as he begins to draw a blueprint of his future with the computer. We have always tended to accept too readily the "conventional wisdom" of the order of wise men, and we now seem to be creating a similar kind of mystique around the computer and its simulations. We are inclined to place too much unquestioning faith in the oversimplifications, routinizations, and quantifications of life; it is tempting to trust the simple numerical results of the computer more than we should. We often proceed too quickly to delegate our work and responsibilities to others; the computer is a glutton for work and responsibility.

It may seem strange to warn against the very things which, in more positive and moderate terms, we previously predicted; particularly peculiar in view of what we have said about natural resistance to machines. But collective man has a dual nature. He is bi-stable. Having accepted an innovation in procedure, albeit begrudgingly, he can then remold himself around it and adopt it as his own. Man's resistance to the unfamiliar is just the other side of his avid attachment to what he has accepted.

The scientist may not be as susceptible in this sense as the average man, but he is not immune by any means. In 1957, for example, a very simple and fast program for generating random numbers made its appearance upon the computer scene. Because of its unprecedented speed, it was adopted as a standard library subroutine by a number of large computer installations, including several of the most prestigious. Random numbers are used in

enormous quantity for a wide variety of computer applications, including Monte Carlo simulations of nuclear interactions and war games. Hundreds, if not thousands, of extremely intelligent people must have used this particular generator in the past nine years. Recently it was found to have serious second-order serial correlation. None of its users was naive enough to believe he was getting genuine random numbers, since that is not in the nature of a programmed machine; and perhaps the serial correlation did not affect the results of most. The fact remains, however, that almost all of these users were ready and happy to put their suspicions aside and accept the quick and convenient pseudo-random numbers provided by the installation under its implicit seal of approval. A few users, to their credit, did conduct their own statistical tests. That is how the aberration was eventually discovered. In post-mortem, it was easy to spot the difficulty by analysis because of the transparent quality of the generator. It would not have been as easy in a more complex generator.

The problem is older than the computer. How many of the executives who base their decisions largely on the biweekly figures of the national Nielson Television Index worry about the size of the statistical sample used to produce these figures? How many concern themselves with whether the sample is fixed ("continuing") and subject to idiosyncracy and tampering? There is a certain magic in the statement that a program is rated third in the nation or was viewed by 29.2 ^{o}/o of families owning television sets. How many executives know that these findings refer to 1000 families under an "area-probability design," and that these families are ones willing to have meters placed on their television sets? How many realize that a rating is determined not only by a program's own merits, but also by the size of the audience it inherits from the preceding program, the strength of its competition,

the time at which it is broadcast in various regions of the country, the number of stations that run it, and the extent to which it is advertised?

The same kinds of questions could be raised about the annual financial report of a corporation, the Gross National Product, figures on unemployment, and countless other sets of numbers and uses of simple formulas. As the computer makes numbers ever more a way of life, producing them by ever more complicated formulas and complex models,we must not lose our ability and desire to question. We must find ways to use the computer itself, and its on-line capabilities, to challenge and rebut. We must pay more attention than ever to the institutionalizing of dissent.

Notes

1. Harlow's monkeys were immobilized when confronted by a totally strange situation. They ventured to investigate the unknown only when in the presence of the mother-figure. In Berlyne's experiments on human exploratory behavior, subjects showed a marked preference for stimuli which were moderately, rather than highly novel.
2. See the other articles in this issue of the Scientific American; especially the one on communications by John Pierce, and the one on time sharing by Robert Fano. One of the first discussions of time sharing is contained in an interesting paper by John McCarthy in Computers and the World of the Future, MIT Press, 1964, M. Greenberger (editor).
3. See, for example, The Shape of Automation, H. Simon, Harper.
4. The history books do not agree on precisely what happened when the supervisor grew suspicious and dropped by to find the lad fast asleep during transmission of the 2 a.m. signal. Whether the outcome was an amused rebuke or a stern dismissal, it is interesting to note that Edison never patented the device.
5. See, for example, the views and concerns of C. P. Snow, Norbert Wiener, and Elting Morison, expressed during a fascinating interchange in Computers and the World of the Future, (above). John Pierce has a paper in this collection entitled, "What Computers Should be Doing;" the controversial aspects of the subject are clearly reflected in the discussion that followed his talk.
6. Microanalysis of Socioeconomic Systems: A Simulation Study, G. H. Orcutt, M. Greenberger, J. Korbel, and A. M. Rivlin, Harper, 1961.

7. *On-Line Computation and Simulation: The OPS-3 System*, M. Greenberger, M. M. Jones, J. H. Morris, Jr., and D. N. Ness, MIT Press, 1965.

8. For an optimistic discussion of the possibilities see, "Banking and the Information Utility," M. Greenberger, *Computers and Automation*, May, 1965; reprinted as "Decline and Fall of the Check," *The Bankers Magazine*, Summer, 1965.

9. For another optimistic discussion of the future, this one on the general concept of an information utility, see "Computers of Tomorrow," M. Greenberger, *The Atlantic*, May, 1964.

10. Paper presented at the December, 1965 meeting of the American Association for the Advancement of Science, Berkeley, California.

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